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GRANULAR FLOW MODULE MINI FACILITY CAPABILITIES FOR GRANULAR FLOW EXPERIMENTS ON THE INTERNATIONAL SPACE STATION

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Abstract

The Granular Flow Module (GFM) is a multi-user mini-facility initially planned to accommodate the needs of three Principal Investigators (PIs) studying the flow of granular materials (simple spheres) in microgravity. The mini-facility is being designed to operate in the Fluids Integrated Rack (FIR) or the Shared Accommodation Rack (SAR) of the Fluids and Combustion Facility (FCF). There are two science configurations being designed to accommodate the science teams. The first is a PI-specific annular Couette cell, with the spheres contained between two concentric cylinders. Anticipated diagnostic capabilities include normal and high-speed video imaging through an optical cover, as well as measurements of the rotational speed, ambient pressure and temperature. The second is a PI-specific annular Couette cell with a rotating end cap, and stress measurement sensors in the other end-cap and cylinders.

Introduction

The GFM is a mini-facility initially designed to conduct three microgravity granular experiments in the Fluids Integrated Rack (FIR) (Ref. 1) on the International Space Station (ISS). The ISS, FIR, GFM mini-facility, and the experiment modules will provide most of the resources and functions. The mission sequence for the GFM hardware and software for the experiment will include the launch on the Shuttle in stowage, ISS facility operations, FIR facility operations, GFM mini-facility operations, three experiment shear apparatus operations, return on the Shuttle, and decommission.

The ISS and the FIR will provide many significant functions and resources. The ISS will provide the space platform and communication to ground for the FIR. The FIR provides an environmentally controlled space. It provides an optic bench, power, cooling fluid and gas, vacuum exhaust, avionics, image processing, data storage, and additional science diagnostic hardware as shown in Figure 1. Specifically, the FIR hardware needed to support GFM includes Fluids Science and Avionics Package (FSAP), PI FSAP, analog camera, Ultra-High Frame Rate (UHFR) Camera, white light source, Nd:YAG 532nm laser, Diagnostic Control Module (DCM), Image Processing and Storage Unit (IPSU), Acceleration Measurement (SAMS) heads, Air Thermal Control Unit (ATCU) and Active Rack Isolation System (ARIS).

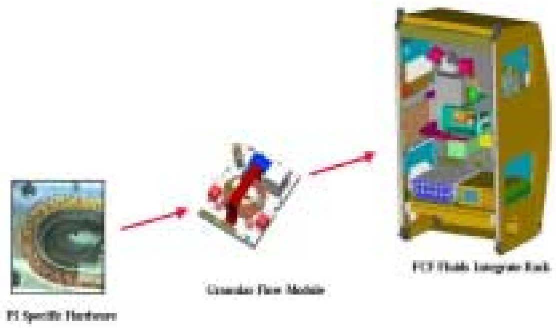

Figure 1 Integrated GFM and FIR concept

GFM utilization

The GFM mini-facility will provide the following general as well as specific capabilities for the experiments: 1) a system to mount the cameras, 2) a supply and remove the spheres, 3) a system to control the rotation of the boundaries, 4) a system for control communication, and data acquisition. The mini facility will permit on-orbit reconfiguration and maintenance that can support follow-on experiments. The design minimizes crew time, power, and up and down mass. The GFM will provide the three experiment shear apparatuses.

The first three experiments include the Microgravity Particle Segregation in Collisional Shearing Flows Experiment (μgSEG; PI, Prof. James T. Jenkins), Studies of Gas-Particle Interactions in a Microgravity Flow Cell (SiGMA; PI, Prof. Michel Y. Louge), and Gravity and Granular Materials Experiment (GGM; PI, Prof. Robert P. Behringer).

The facility is designed to have interchangeable experiment shear apparatuses. The μgSEG and SiGMA experiments will be fairly similar with rotating cylinder walls. The GGM experiment shear apparatus will have a similar footprint with a rotating end-cap and fixed cylinder walls.

The system will provide for on-orbit operations through imbedded software. The software will control the experiment operations, data collection, and data transfer to ground. The system will also provide for ground control. The facility is designed to minimize vibration transmission to the experiment shear apparatus, FIR, and the ISS.

Microgravity Particle Segregation in Collisional Shearing Flows of Binary Mixtures of inelastic Spheres

The objective of the μgSEG experiment is to test mechanisms of granular segregation that are not controlled by gravity. When gravity is absent and the grains flow fast enough that the grain-grain interactions are only elastic (or slightly inelastic) collisions, the kinetic theory of gases governs the motions of the grains (Ref. 2). Recall that kinetic theory describes the gas molecules as endowed of a mean velocity with velocity fluctuations about the mean. Just as the gas temperature is a measure of the mean of the fluctuation velocity squared, so is the "granular temperature" defined as the mean of the square fluctuation velocity. This theory predicts that a binary mixture of grains will segregate based on particle size or on particle mass as long as a gradient of velocity fluctuation is present in the flow. This space experiment is one element of a three-pronged approach, the other two being kinetic theory and molecular dynamics (MD) simulations.

In the experiment, the required distribution of granular fluctuation energy will be controlled by fitting the rotating cylindrical walls with "bumps" having specific shapes and collision properties. The key diagnostic is digital video of the particles' trajectories between the rotating walls. From the trajectories we will extract mean velocities and fluctuation energy across the cell for each species. The measurements will be compared to theory and to MD simulations.

The experiment will isolate and investigate two different sub-mechanisms of collisional segregation that usually occur together. The first is associated with differences in the inertia of the spheres and the second is associated with the differences in the geometry of the spheres. Inertial segregation will be studied in a system of spheres with different masses, but equal diameters. Geometric segregation will be studied in a system with different diameters, but equal masses.

The GFM hardware for μgSEG and SiGMA consists of the optics system turntable, counter rotating inner and outer bumpy boundaries, and a channel or experiment section (Fig 2-a, b, c). The rotating boundaries are fitted with appropriately shaped bumps that impart velocity fluctuations to the moving grains. The instrument consists of an axisymmetric shear apparatus with counter rotating cylindrical boundaries (Ref. 3). The boundaries will be able to move in opposite directions as speeds ranging from 0.0 to 1.096 rad/sec and –1.096 to 0.0. The top plate will be flat, smooth and contain windows for sphere tracking. The imaging system located on the top end cap will be able to distinguish between the two types of spheres. The images are analyzed by a PI-designed algorithm able to track the trajectories of individual particles. The base will be flat. The facility will provide a system to supply and remove the spheres to change the sphere type and mixture. The humidity will be controlled by flowing dry nitrogen through the experimental apparatus.

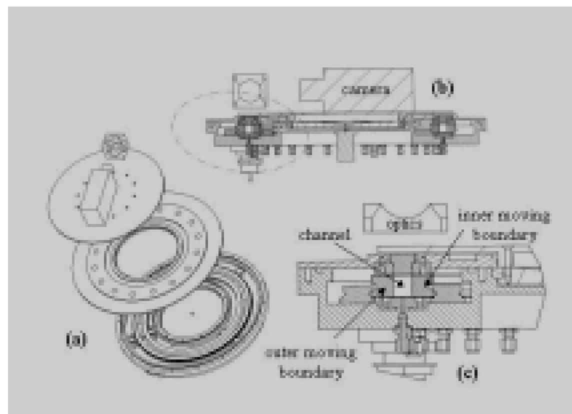

Figure 2 – Images of the current ground based shear apparatus a) expanded view of optics, top plate, and Couette, b) general view of the experiment shear apparatus, c) cutaway of the experiment section.

Studies of Gas-Particle Interactions in Microgravity Flow Cell

The SiGMA experiment will study the viscous dissipation of fluctuation energy in flows that have negligible relative mean velocities between the phases (viscous dissipation case) and to investigate the effects of a mean relative velocity between the phases on the particle phase momentum (viscous drag case). In order to bring the effect of viscous dissipation in the gas, the Stokes number (measuring the ratio of the particle's inertia to the viscous forces exerted by the gas on the particle) must be moderate (cf. μgSEG where the Stokes number must be large to ensure a purely collisional regime). This means that both the particle density and the relative velocities of the rotating boundaries cannot be too large.

In this experiment we will measure the viscous dissipation and viscous drag coefficients at several volume fractions of a single species of grains. In order to test the theories available to describe these regimes, partial evacuation of the cell is required.

SiGMA has many of the requirements stated for μgSEG (Figure 3) with different rotational and counter rotational speeds (Ref. 4). Capacitance probes will be used to measure the mean solid volume fraction. When used in combination with the gas flow rate, this measurement determines the gas velocity. Alternatively, the experiment may have tracer particles to determine gas velocity.

The GFM and SIGMA experiment shear apparatus will provide an annular axisymmetric channel with a rectangular cross section. The facility provides a 16 viewing windows with an imaging system to capture view and track the spheres' trajectories from the end cap. The optical system is capable of automatically rotating the high-speed camera over any of the 16 viewing windows. The facility provides for counter rotating inner and outer bumpy boundaries. The facility will provide a system to supply and remove the spheres to change the sphere type. The humidity will be controlled by flowing dry Nitrogen through the experiment shear apparatus.

Gravity and Granular Materials

The GGM experiment will characterize general properties of granular materials under shear in both the dense and dilute phases. The experiments will focus on two granular phase transitions. The first is the phase transition that occurs for dense sheared granular materials as the density passes through the critical value. The second is the clustering instability (Ref. 5).

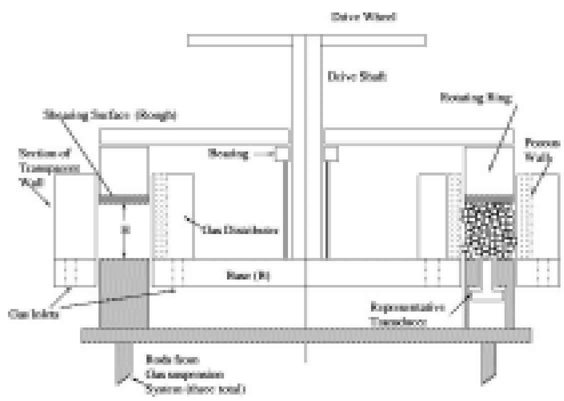

Figure 3 – Schematic cross section of current ground based shear apparatus.

GGM requires a very different apparatus. The GFM mini-facility and the GGM experiment shear apparatus will provide an axisymmetric system with a variable rectangular test section. The end cap will move at speeds from 0.033 to 60.0 rev/min. The facility provides for a rotating end-cap with a bumpy surface. The facility will measure shear and normal stress developed in the granular chains and energy (particle pressure in the gas phase) transfer. The variable cylinder height will be adjustable to allow for a single layer of spheres up to 100 layers. The facility will provide for a loaded bottom plate and the ability to fix the plate. The system will have the ability to operate in a fixed pressure and fixed volume mode. The facility provides a single viewing window with an imaging system to capture the spheres through the cylindrical. The facility will provide a system to supply and remove the spheres to change the sphere type. The humidity will be controlled by flowing dry N_2 through the experiment shear apparatus.

Summary

The GFM mini facility is a unique apparatus designed to operate in the FIR aboard the ISS. The facility is being designed to conduct three granular experiments. The facility is designed to enable on-orbit reconfiguration and maintenance that can support follow-on experiments. The facility supplies, in addition to resources from the ISS and FIR, several significant capabilities including a high speed imaging capability capable of imaging 360 degrees, two drive systems, and the ability to change the volume of the experiment section. The experiment shear apparatuses are designed to be modular to allow modules to be interchanged into the apparatus.

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